Bioaccumulation-Based Sediment Quality Values

Onondaga Lake, NY

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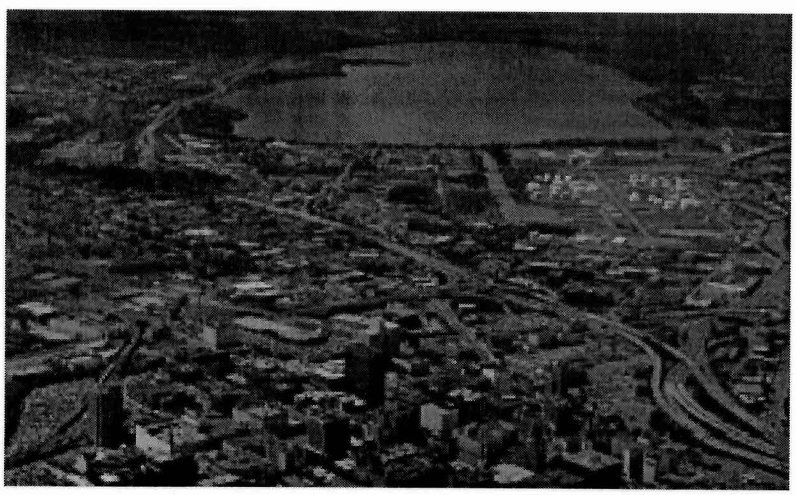
Exponent

December 23, 1999



This document contains graphics and brief explanatory text from a presentation on bioaccumulation-based sediment quality values by Honeywell to the New York State Department of Environmental Conservation on December 23, 1999, in Albany, New York.

This presentation describes a proposed approach for developing sediment quality values protective of the aquatic food web and piscivorous and benthivorous wildlife in Onondaga Lake against the adverse effects of methylmercury and total PCB bioaccumulation. This approach provides a method to predict methylmercury and total PCB concentrations in specific trophic levels of the aquatic food web. For simplicity's sake, only aquatic species are discussed in this presentation; however, Honeywell recommends extending the approach in the ecological risk assessment to include wildlife species that use various components of the aquatic food web as a food source.

This presentation also summarizes the data upon which this analysis can be founded.

Mercury Bioaccumulation in Onondaga Lake

- **Methylmercury and PCB transfers through food webs**
- **Piscivorous fish feed throughout lake**
- **Mercury and PCB concentrations are lakewide averages**

Bioaccumulation-Based Sediment Quality Values

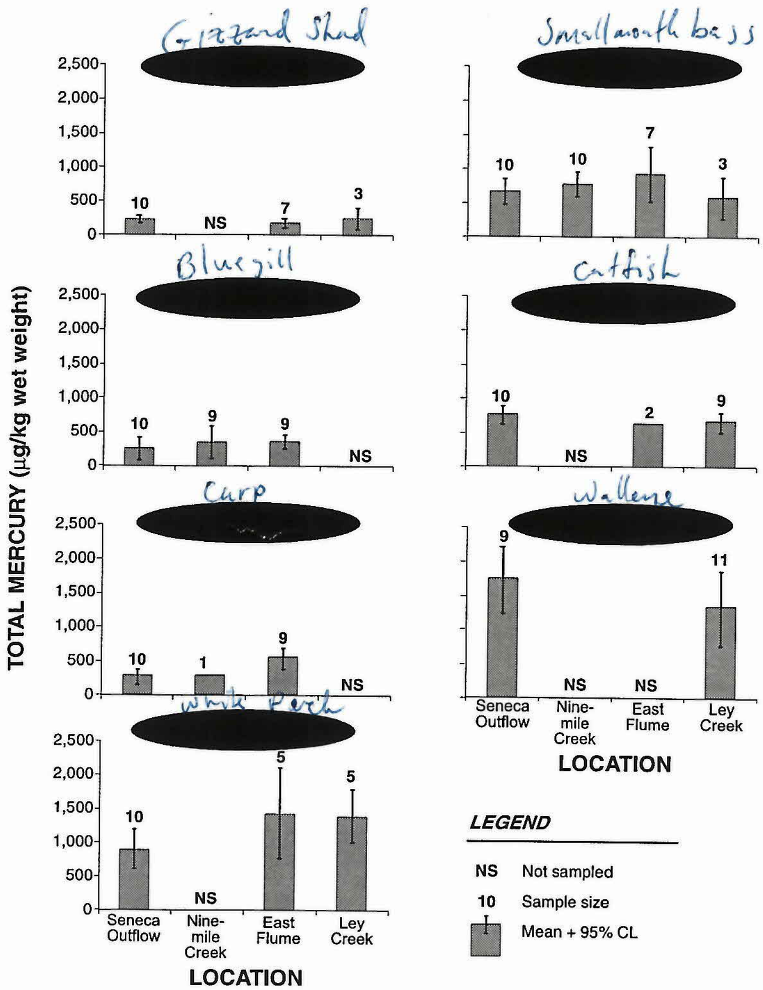
Exponent

The proposed approach is based on determining the degree of methylmercury and total PCB biomagnification along the two predominant food chains—pelagic and benthic—that compose the Onondaga Lake food web. For example, based on existing data, the increase in methylmercury in fishes that feed predominantly on zooplankton compared to the average concentration in zooplankton can be calculated. This simple factor, generally referred to as a bioaccumulation factor (BAF), can be calculated for all of the links in the Onondaga Lake food web and used to predict methylmercury concentrations in the various levels of the food web based on alternative average water and sediment quality conditions. The same method can be used for PCBs. It should be noted that this approach assumes that BAFs remain constant.

The proposed approach also assumes that methylmercury is transferred through the food web primarily via food ingestion. Although methylmercury and PCBs can be absorbed via gill surfaces, and there is some evidence that mercury can be methylated in a fish's gut, these exposures are small and are not considered in these calculations.

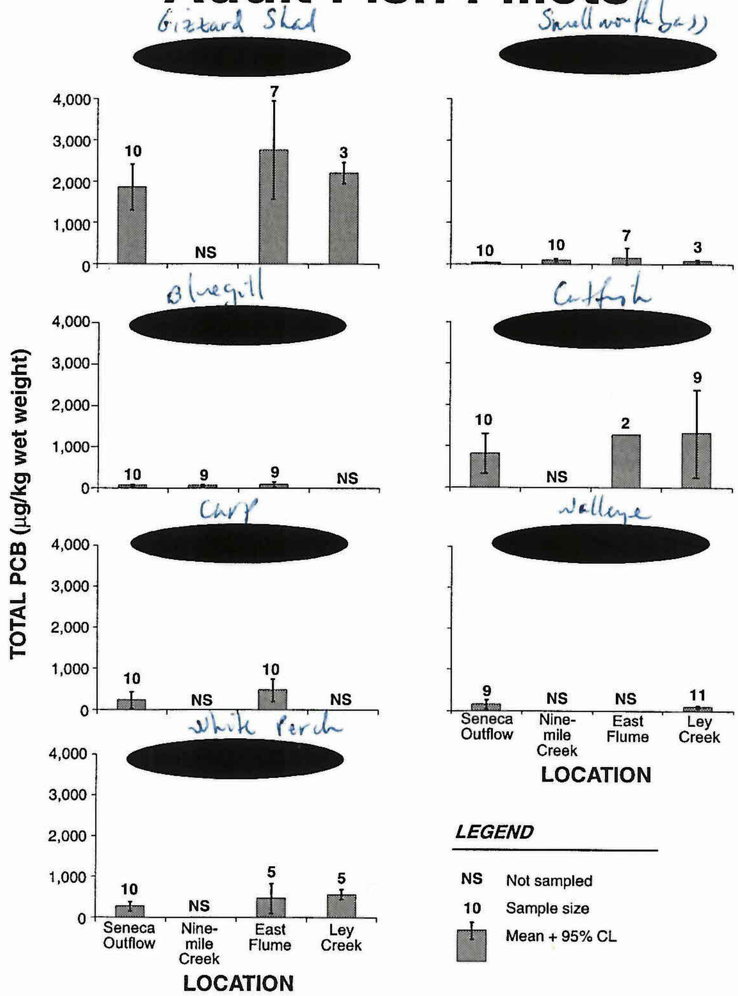
Another assumption is that piscivorous and benthivorous fishes feed throughout the lake. This assumption is based on the low spatial variability exhibited by the 1992 data, as shown in subsequent slides. Thus, the average concentrations of methylmercury and PCBs in sediment and benthic macroinvertebrates are sufficient to characterize the sediment-related contributions of methylmercury and PCBs to the aquatic food web.

Mean Mercury Concentrations in Whole Adult Fish



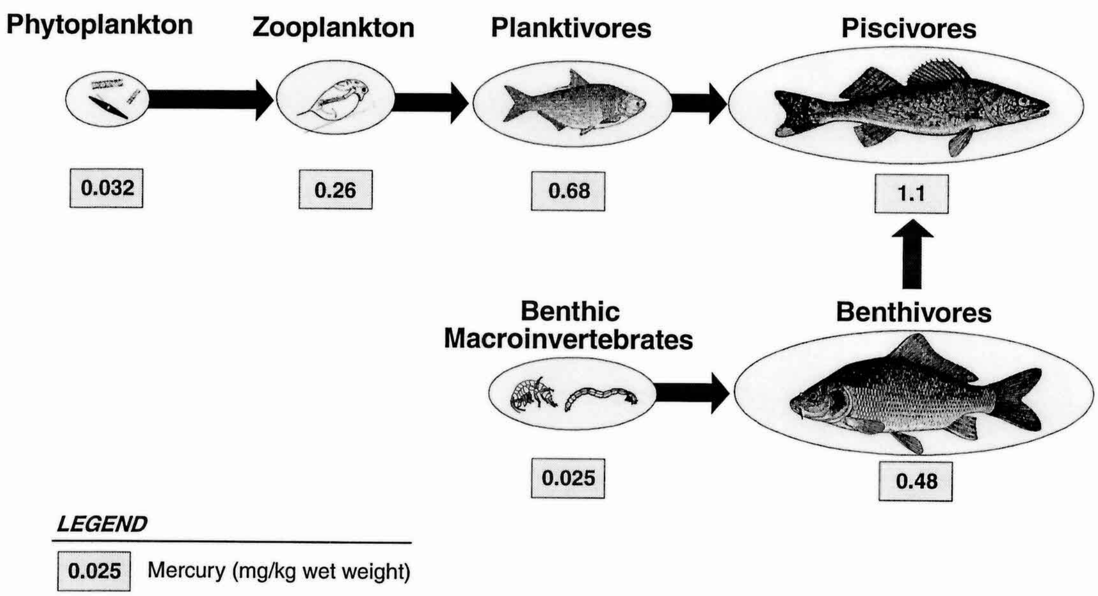
This graphic presents the mean total mercury concentrations in seven fish species collected in 1992 at four locations in Onondaga Lake. Note that some species were not captured at all locations, as indicated by the symbol NS. Only one species, carp, shows a statistically significant difference among the sample locations. The distributions of fish ages were similar among the various locations and did not significantly skew the results.

Mean PCB Concentrations in Adult Fish Fillets



This graphic presents the mean PCB concentrations in the seven fish species collected in 1992 at four locations in Onondaga Lake. These data represent the sum of detected Aroclor® concentrations on a wet-weight basis and have not been standardized to lipid content. Two species, smallmouth bass and white perch, exhibited a statistically significant difference among sample locations: the bass had higher PCB concentrations in East Flume and Ninemile Creek than in the Seneca River outflow, and white perch had higher PCB concentrations in Ley Creek than in East Flume and the Seneca River outflow.

Onondaga Lake Food Web

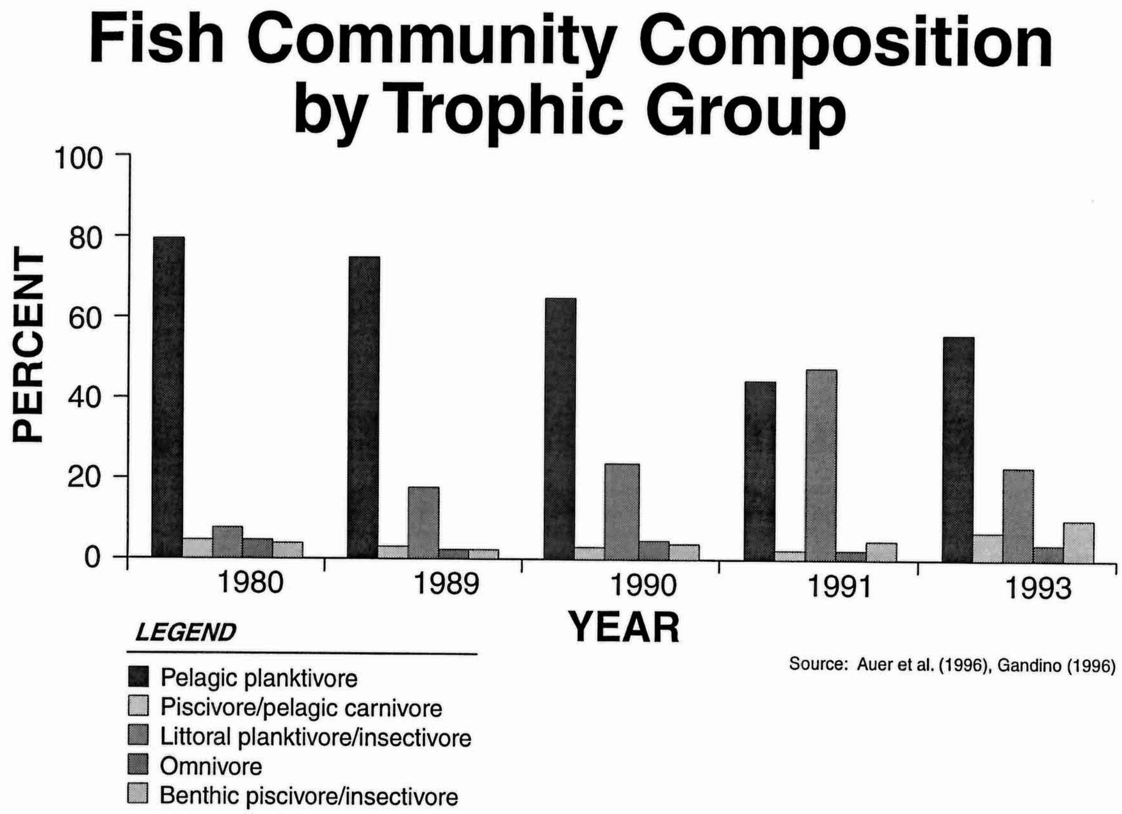


The Onondaga Lake aquatic food web contains two primary contaminant exposure pathways. Contaminants in water adsorb onto the surfaces of phytoplankton, which are present throughout the lake. Zooplankton prey on phytoplankton and effectively concentrate the bioaccumulative compounds present in the phytoplankton. Planktivores (fishes that prey predominantly on zooplankton, and in some cases phytoplankton) continue the same process of bioaccumulation and biomagnification. The planktivores are preyed upon by fish-eating fish (piscivores). This contaminant exposure pathway is referred to as the pelagic pathway, or pelagic food chain, because it involves contaminants and aquatic organisms that reside in the water column.

The other primary exposure pathway is the benthic pathway or food chain, where contaminants are derived from sediment or from the interstitial water associated with sediment. Contaminants are taken up by benthic macroinvertebrates along with ingested sediment and microorganisms. Certain fish species in Onondaga Lake prey predominantly on benthic macroinvertebrates and thus bioaccumulate and biomagnify contaminants in the same way as in the pelagic food chain. Note that the top predators (piscivores) derive their food and contaminant exposure from both the pelagic and benthic food chains.

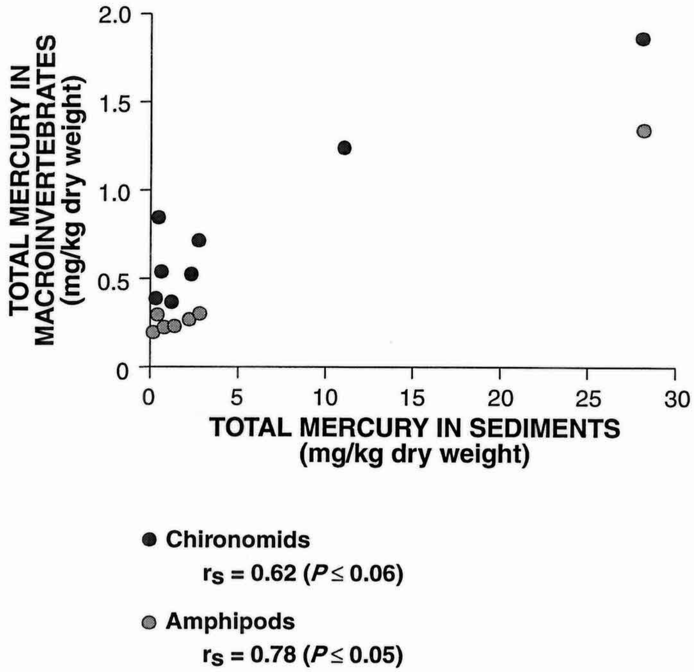
The number associated with each member of the aquatic food web is the average total mercury concentration based on the 1992 data. These values (in the form of averages or distributions) can be used to calculate BAFs. For example, the BAF for benthivores is about 20; i.e., benthivores have about twenty times the average concentration of methylmercury as do benthic macroinvertebrates.

This graphic also provides a textbook example of how food chain length influences bioaccumulation. One reason that the planktivores have a higher average concentration than the benthivores is that the pelagic food chain is longer. This phenomenon has also been illustrated by results of studies performed by Dr. Charles Driscoll, of Syracuse University, in Adirondack lakes.



This graphic illustrates the relative abundance of the pelagic versus benthic components of the Onondaga Lake food web and their temporal variability. The data are from studies performed by Dr. Neil Ringler's students at SUNY ESF. The categorization of the food web is a bit different from that shown in the previous slide, but illustrates that pelagic and planktivorous species are the most abundant species in Onondaga Lake. Relative abundance of the pelagic and benthic food webs should be included in any food web bioaccumulation calculations.

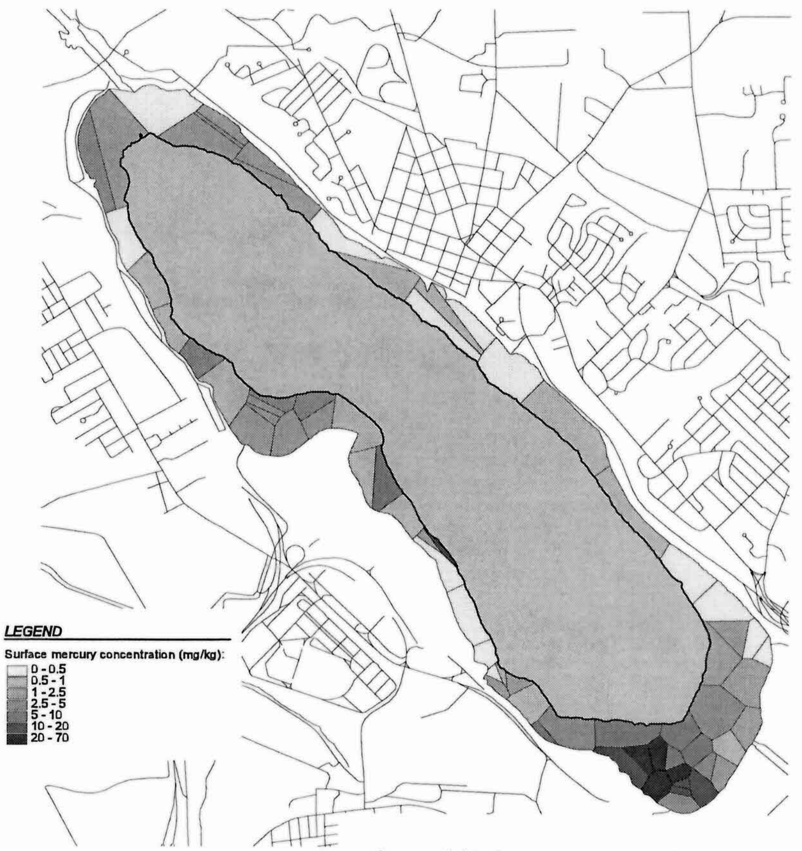
Comparison of Total Mercury Concentrations in Benthic Macroinvertebrates and Sediments



The approach to calculation of a BAF was shown previously, but a method to relate sediment contaminant concentrations to contaminant concentrations in benthic macroinvertebrates is still needed. With this information, contaminant concentrations in sediments can be linked to concentrations in fishes.

This graphic displays the 1992 data from which a mercury BAF for two of the dominant benthic macroinvertebrate taxa can be calculated. In both cases, the correlations are relatively high. However, in both cases, the relationships lack moderate values. This condition indicates that additional data should be collected with which to establish a more solid foundation for food web bioaccumulation calculations. Also, a relationship based on methylmercury rather than total mercury would be more useful.

Mercury Concentration in Surface Sediment of Onondaga Lake



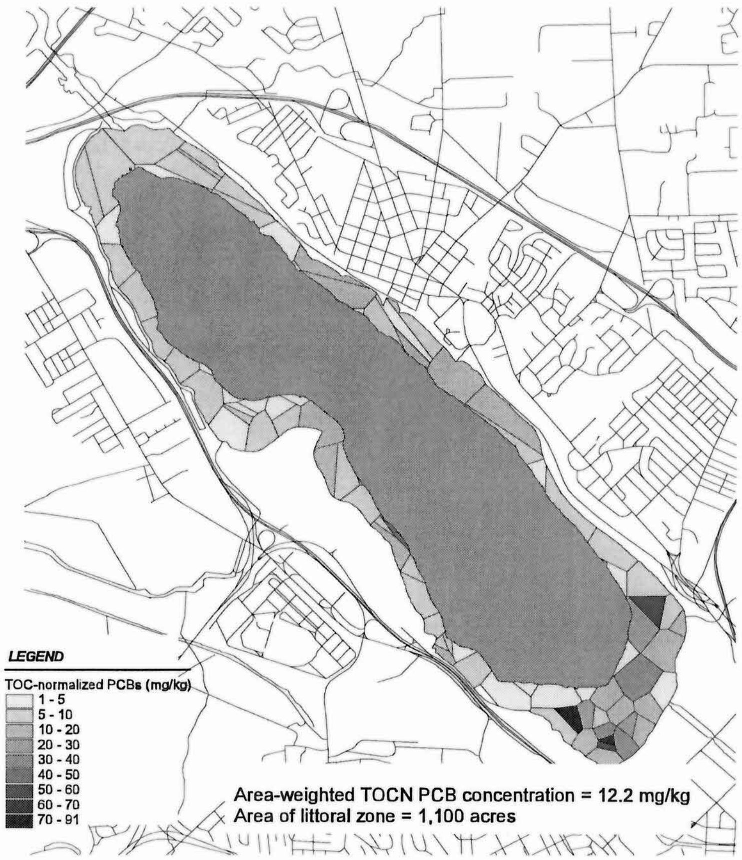
Area-weighted mercury concentration = 2.96 mg/kg
Area of littoral zone = 1,100 acres

This and the next several graphics summarize much of the data needed to calculate mercury bioaccumulation in the Onondaga Lake food web. This graphic provides a summary of total mercury concentrations in surface sediments (0–2 cm) of the littoral zone (less than 10 m water depth), based on a nearest-neighbor interpolation.

As noted earlier, food web bioaccumulation calculations should be based on the average concentration (2.96 mg/kg) of the zone where sediment-related exposure occurs. During periods of lake stratification, this zone is the littoral zone, including sediments in water depths down to 9–10 m during approximately April through November. In December through May, fish could seek prey in the deeper waters of the profundal zone; however, their feeding rates are lower during this period and it is doubtful that significant benthic biomass could develop in this short time before anoxia is reestablished. Therefore, the deeper sediments are not considered in calculating food web bioaccumulation. Note also that mercury concentrations in most profundal-zone surface sediments are generally below the littoral-zone average of 2.96 mg/kg.

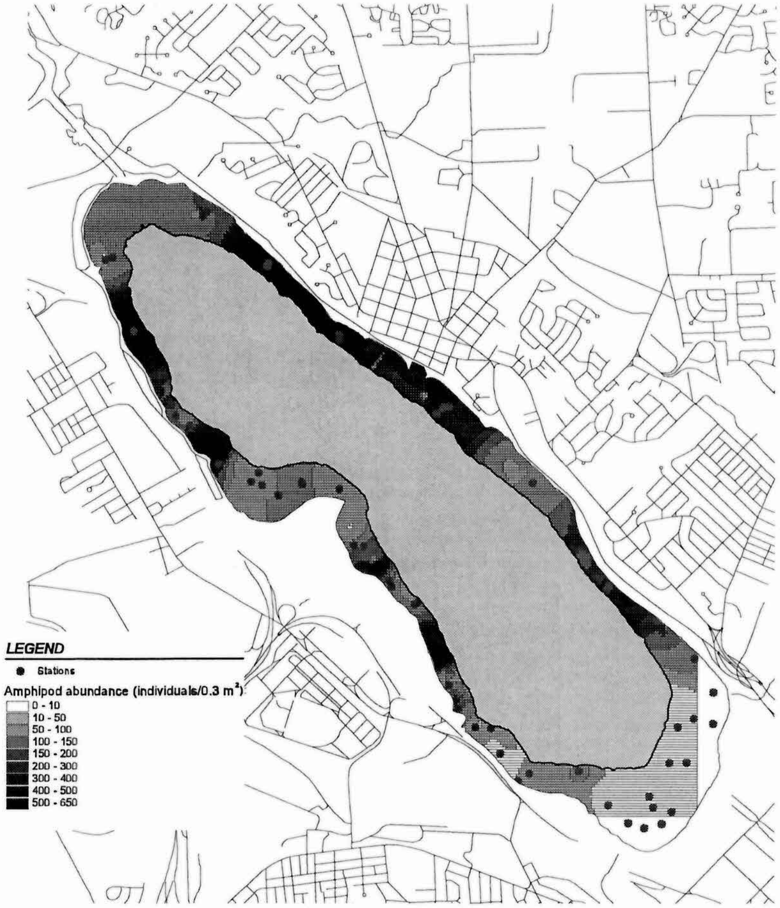
The quality of littoral-zone sediment will continue to be the most relevant consideration for bioaccumulation calculations in the future even if the whole lake remains aerobic throughout the year. At most, the most relevant area may extend somewhat beyond the 9–10 m depth. This is true because water clarity limits sight-feeding fishes to shallower waters, and temperature limits warm-water fishes to the epilimnion. Also, benthic macroinvertebrate diversity and density typically decline with water depth.

Surface Sediment TOC-Normalized PCB Concentration in Onondaga Lake



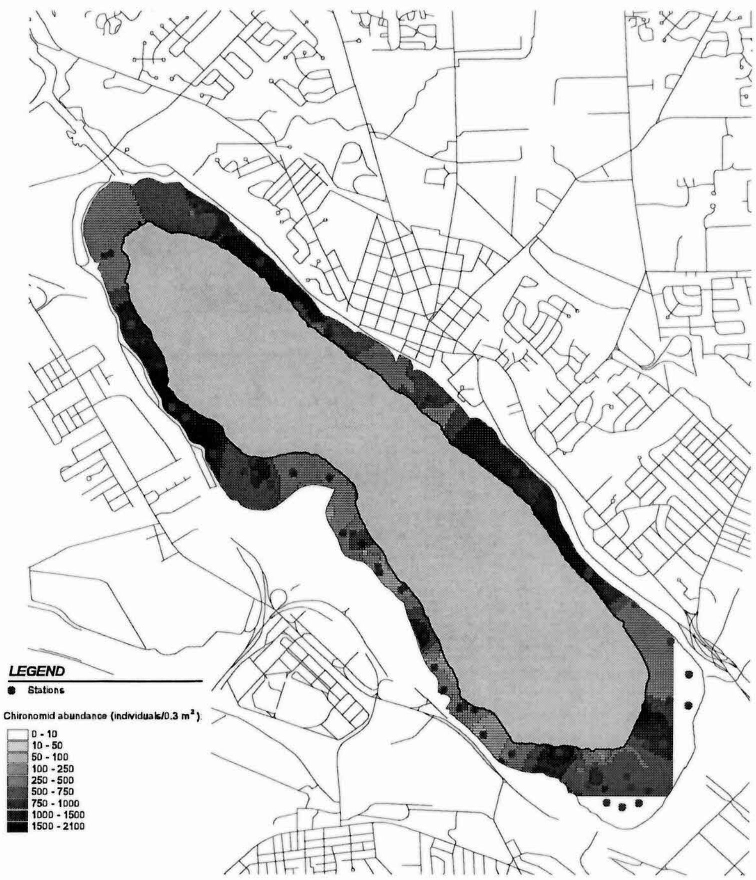
This graphic presents PCB concentrations for littoral-zone sediments using the same interpolation methods as in the previous graphic. In this graphic, the total PCB concentrations are normalized or standardized to (divided by) TOC concentrations.

Amphipod Abundance Distribution in Onondaga Lake



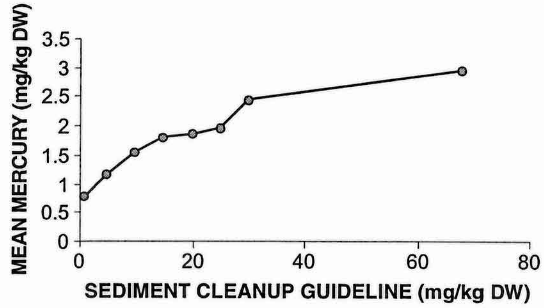
This graphic and the next illustrate the spatial variability of amphipods and chironomids, respectively. These are presented simply to illustrate the data collected in 1992. We propose that bioaccumulation calculations assume that the benthos are evenly distributed. This is appropriate because a roughly even distribution is apparent from the two graphics, with the exception of amphipods in the southern end of the lake. The evenness of the distribution should increase in the future as sediment quality improves.

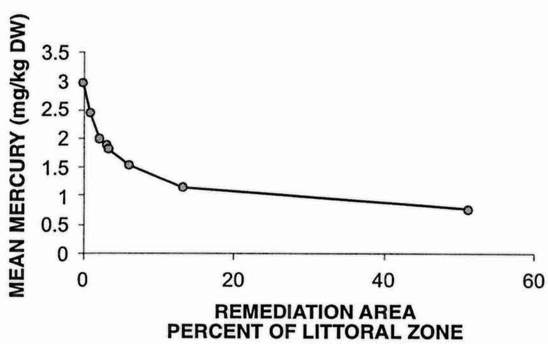
Chironomid Abundance Distribution in Onondaga Lake



Note that chironomids are more abundant and more evenly distributed than amphipods.

Change in Average Mercury Concentration with Cleanup Area





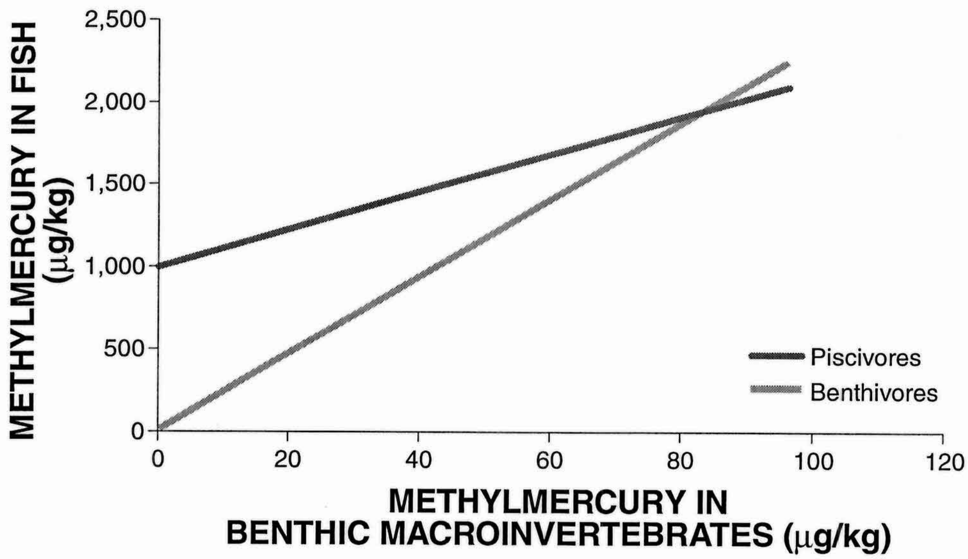
Note: Assume areas with mercury greater than sediment cleanup guideline would be remediated to a residual mercury concentration of 1.0 mg/kg dry weight (DW)

As noted earlier in graphic number 8, the average mercury concentration in littoral-zone surface sediments is 2.96 mg/kg, based on 1992 data. It was also noted that the average concentration of mercury in littoral-zone surface sediment is the most relevant value for use in food web bioaccumulation calculations. This graphic illustrates how the average concentration of mercury in littoral-zone surface sediment could change if particular blocks of sediment, as shown in graphic number 8, were reduced to 1.0 mg/kg.

The upper plot illustrates how the choice of sediment mercury concentration guideline affects the average concentration of mercury in littoral-zone surface sediment (the value used in bioaccumulation calculations). The graph indicates, for example, that if the sediment quality guideline is set at the current maximum mercury concentration of about 70 mg/kg, the mean is almost 3 mg/kg. This, of course, is the current mean mercury value based on the 1992 data. The graph also indicates that, if all of the blocks in graphic 8 with mercury concentrations greater than 20 mg/kg were reduced to 1 mg/kg, the average concentration of mercury in littoral-zone surface sediment would be reduced to around 1.8 mg/kg.

The lower plot in graphic 8 shows the area of sediment that would have to be remediated (dredged or capped) to meet the sediment cleanup guidelines presented in the upper plot. For example, to achieve the average concentration of 1.8 mg/kg noted above, about 200,000 m^2 of lake sediment would have to be remediated.

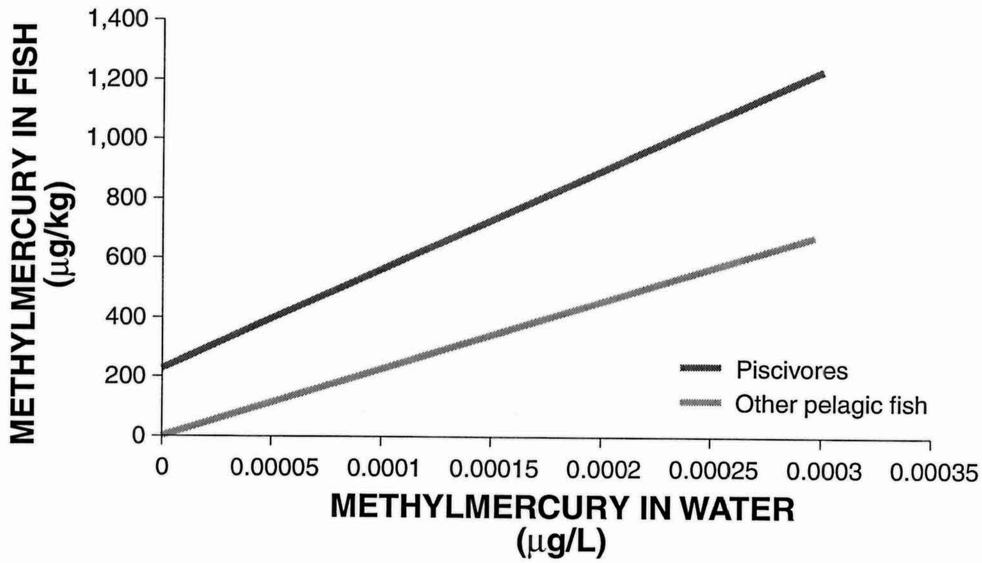
Mercury in Fish Based on Changes in Benthic Macroinvertebrate Mercury Concentrations



This graphic shows the results obtained if the existing BAF relationships are used to predict mercury concentrations in fish tissue under alternative contaminant concentration scenarios. Note that the results are based on alternative mercury concentrations in benthic macroinvertebrates. The graphic could also be based on mercury concentrations in sediment if the relationships between sediment and benthic macroinvertebrates (graphics 10 and 11) were used. The calculations shown here also assume that the concentration of mercury in the pelagic food chain (which influences piscivore but not benthivore methylmercury concentrations) remains constant.

These simple calculations illustrate the fact that sediment remediation can be expected to reduce mercury concentrations in the benthic food web. However, even complete removal of mercury from benthic macroinvertebrates, which would be impossible, would not lower the mean mercury concentrations in piscivorous fishes below 1.0 mg/kg. This, of course, is because piscivorous fishes receive most of their mercury exposure through the pelagic food web.

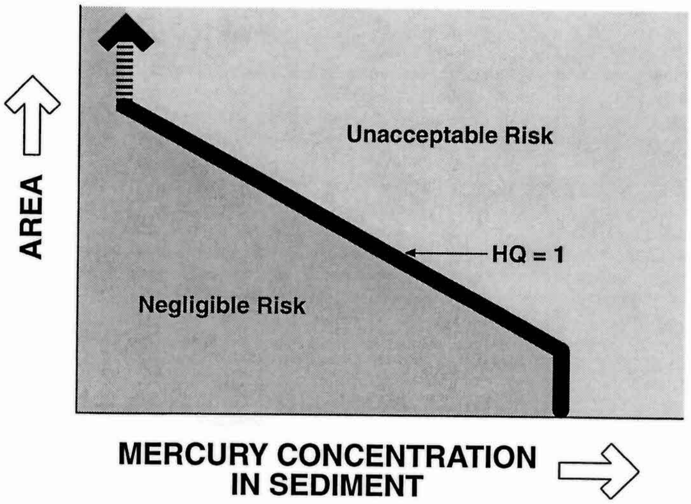
Mercury in Pelagic Fish Based on Changes in Mercury Water Concentrations



This graphic is similar to the previous graphic but, in this case, mercury exposure through the benthic food chain remains constant while mercury concentrations in water change. The graphic shows the expected result: that reduction of mercury concentrations in lake water can effectively reduce mercury concentrations in pelagic fishes. However, reduction of mercury concentrations in piscivorous fishes is limited by the contribution from the benthic food chain.

When graphics 13 and 14 are compared, it is clear that reductions of mercury concentrations in water should be far more effective in reducing mercury concentrations in piscivorous fishes than reduction of mercury exposure from the benthic food chain.

Risk Depends on Area and Concentration



In summary, mercury exposure to the aquatic food web of Onondaga Lake from the benthic food chain is related to the average concentration of mercury in littoral-zone surface sediment. It is therefore not practical to think of a single sediment quality value that would protect human and ecological receptors from risks of mercury bioaccumulation. Instead, as shown conceptually in this graphic, risk managers should focus on both the mercury concentration and the area of coverage of that concentration because these are what influence the average concentration to which fish are actually exposed. This graphic illustrates that relatively high mercury concentrations may be acceptable as long as they cover only a small area. As the area of coverage increases, the acceptable mercury concentration decreases.

Rather than develop a single bioaccumulation-based sediment quality value, we suggest that the calculations illustrated above, based on simple BAF relationships, can be used to demonstrate semiquantitatively how fish tissue mercury concentrations can be reduced under alternative sediment and water column mercury concentration scenarios.